Asset information management using Linked Data for the life-cycle of Roads

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ABSTRACT: From September 2016 to August 2018 a CEDR (Conference of European Directors of Roads) research has been conducted by the consortium INTERLINK into asset information management for European Roads life-cycle management using Linked Data. This research aims to improve interoperability between the European National Road Authorities (NRAs) and their stakeholders, mainly to explore the procurement of road asset information by NRAs for better operations, asset management and project management, to investigate suitable data structures for asset information, including BIM and GIS, to develop common principles for a European Road object type library (OTL) and to design and test a basic European Road OTL connected to open BIM/GIS standards. The CEDR INTERLINK project will design a managed European Road OTL as the basis of a common language to be used for developing high quality national Road OTLs for exchanging and sharing road asset data. This European Road OTL is supported by three pillars to optimize the success of subsequent implementation: 1. a quality open available standardized Technical Specification, 2. a suitable and sustainable Standardization Body, with a plan for development beyond this project and 3. acceptance in practice by the industry through engagement and dissemination. First the business and data needs have been investigated by INTERLINK through a literature review, interviews with stakeholders (NRAs, contractors, consultants, suppliers, academics, software developers and standardization initiatives in Europe) and an industry survey, which resulted in a approach for the European Road OTL. The common principles, based on the requirements, describe a hybrid solution, with semantically-rich data referencing more traditional document-based information, combining the strengths of currently applied BIM/GIS standards with Linked Data / Semantic Web technology. The proof-of-concept European Road OTL is tested via three trial cases, which demonstrated data transfers representing typical processes during assets' life-cycles in three European countries: Germany, Sweden and The Netherlands. A road map is delivered for development and implementation of the Road OTL from document based to object based road information management based on the European Road OTL open standard using Linked Data.

1 INTRODUCTION

The Conference of European Directors of Roads (CEDR) aims to improve interoperability within the European National Roads Authorities (NRAs) and its stakeholders by embedding the use of Building Information Management based on open standards in their Asset Management and Construction processes. CEDR started a research programme in 2015 to improve interoperability within the European NRAs and their stakeholders. CEDR aims to embed the use of Building Information Modelling (BIM) based on open standards in the NRAs asset managements and construction processes for life-cycle road asset management. This new pan-European initiative is conducted by the consortium INTERLINK to provide NRAs and their supply chain with future-proof information management standards using Linked Data (LD) for a proposed European Road OTL, to use as the open available standardized one-language basis in the multi-language supply chain for life-cycle road asset management, for the delivery and operation of infrastructure assets. In this paper the proceedings will be presented of this research with the needs investigations, the common principles and three test cases of the European Road OTL.

1.1 *The objectives*

The main objectives of the INTERLINK research are to explore the procurement of road asset information by NRAs for better asset management, to investigate suitable data structures for asset information, to develop common principles for a European Road OTL and to design and test a basic

European Road OTL connected to existing open standards (Luiten et al, 2017).

1.2 *Object type library for life-cycle road asset management*

An OTL in general is an abstract, simplified view on a part of reality to be represented for some purpose: to support a common understanding between humans and computers of information required for the design, planning, construction, operation and maintenance of road infrastructure assets (O'Keeffe et al, 2017).

The OTL is a library with standardized object types (e.g. road, viaduct) and properties, interrelationships and constraints. An object is described with its object type data, geometry data and metadata. Metadata are data about the data of objects (like owner, author, version, creation date etc.). The object types, properties, relationships and constraints are grouped in what is called an 'ontology'.

An OTL can be used as the data structure to control the actual asset data that are being dealt with in applications, shared in asset management processes and managed by asset owners. These data have the object types as their type and values and references for the defined properties and relationships. The constraints can be utilized to validate the data, i.e. determine whether they comply with the OTL.

By using an OTL, road assets are described with a standard language, standard syntax and semantics, which are required for a reliable exchange and sharing of road asset information for life-cycle road asset management.

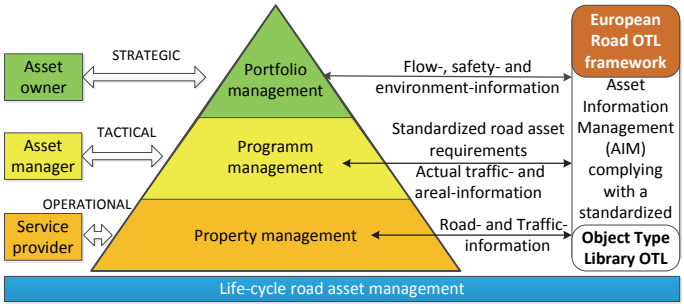

Figure 1. The use of an object type library for life-cycle road asset management.

During the life-cycle, information on assets, complying with a standardized OTL, e.g. the European Road OTL, is linked to other open available information sources about the roads, traffic and its environment. This facilitates strategic, tactical and operational decisions for life-cycle road asset management, as shown in figure 1.

2 BIM BUSINESS NEEDS AND DATA NEEDS

The business needs and data needs to meet the business needs for road asset information with BIM and Linked Data are investigated by INTERLINK with a literature review, interviews with stakeholders and an international survey. The 63 interviewed stakeholders were NRA delegates, NRA asset managers, ICT companies representatives, AEC consultants, research institutes, BIM consultants and contractors of different European countries. This research resulted in a set of requirements for road asset information management, represented as 40 needs statements (O'Keeffe et al, 2017).

The main business need statements are:

- Asset information management should facilitate a gradual transition of existing asset information to smart information (semantically rich information).
- The organization that maintains the European Road OTL should be independent and supported by industry.
- The standardization body responsible for the European Road OTL should publish a road map for standardization in order to inform strategic planning at national and organizational level.
- Relevant asset information should be gathered and updated systematically over the life-cycle of an asset, from its inception through design, construction, inspection, maintenance, and renewal.
- Contractors should be required to handover to the asset owner a set of quality assured, certified as-built graphical and non-graphical information.
- Common European standards for information management of road infrastructure assets should be based in English, with the possibility to translate to other languages.

The business needs focus on the gradual transition to smart information, reliable and open information exchange about the road assets, multi lingual, concerning all aspects of roads (costs, tolerance and risks).

The main data need statements are:

- Road asset information systems should be based on open information management standards.
- National information management standards for road assets should be based on relevant international standards.
- Asset information systems should enable access to information through GIS (geographical information systems).
- The European Road OTL should accommodate linking to IFC-Road, IFC-Alignment and IFC-Bridge once that standard is published and adopted.
- Standards for exchange and sharing of asset information should be built on established open web standards.

• Design checking, design approval and as-built approval should be conducted using object data with associated model data (e.g. 3D models).
• The owner of shared asset data should be clearly identified (e.g. within metadata).
• Although the value of some as-built unstructured construction quality documentation (e.g. material test results, method statements) may not be apparent to asset managers at the time of handover, such data may present value in the future and should be linked through standardized objects.
• In project and asset information systems, all terms and attributes should have an associated definition to facilitate common understanding.

The data needs focus on standards, reliable data, linked data, robust for the future and defined. As a result of these investigated needs the needs per stakeholder can be summarized in the table below.

Table 1. Needs per stakeholder

Stakeholders	Needs
CEDR members, NRAs	Efficient and effective Asset Management Information system (business need).
Contractors, suppliers, Consultants, Architects, Engineers CAE	Successful collaboration with CEDR members NRAs by efficient Information exchange/sharing (business need).
ICT industry	Business case for the European development and operation of Information Management tools (data need).
Standardization bodies	Development of international standards (data need).
BIM consultants	Exploration and dissemination of BIM for Asset Management (business and data need).

These statements and needs are used to inform and steer the development of a basic European Road OTL.
From this research into the needs and the as-is situation it can be concluded that the as-is process is predominantly document based, with silo databases and inconsistent information requirements. Asset road information is exchanged with suppliers by copying the data and not integrated with project and operations systems. Due to these issues, data used is often incomplete, outdated, inconsistent, non-uniform and not directly usable, thereby presenting extensive risks to NRAs (Luiten et al, 2017).
A European Road OTL can be used when developing a data platform. Such a platform can be used for sharing or exchanging information. In general, sharing is preferable because if information is shared, it remains at the information owner. This owner organization is responsible for maintaining the information with semantically-rich content, keeping it up to date, and giving third parties access to that data.
Data should be shared easily; Internet, W3C offers generally accepted techniques for LD/SW; advantages of these techniques are defined in the figure below. The figure summarizes the benefits of Linked Data and Semantic Web (SW) technology when applied to an OTL. Therefore we choose to use LD/SW. This is in line with international developments.

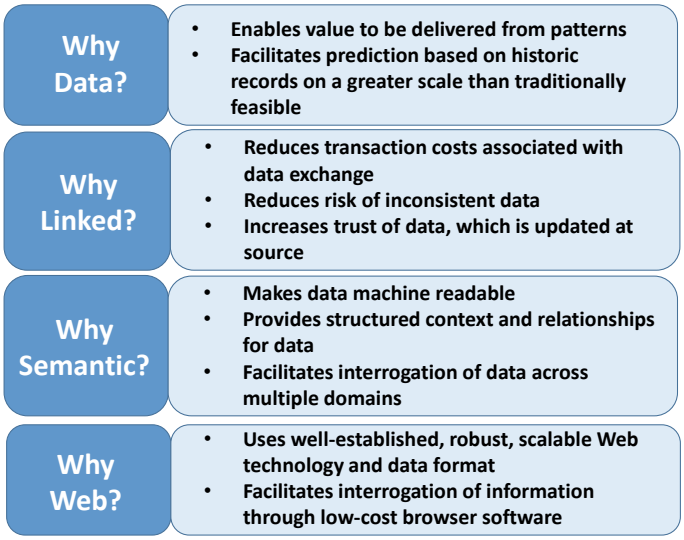

Figure 2. The value of LD/SW technology for the European Road OTL (O'Keeffe et al, 2017).

2.1 *Standards*

For road Asset Managers like the NRAs it is of crucial importance that the European Road OTL facilitates the mapping of the existing country specific ontologies and information models (like the CB-NL in The Netherlands, BSAB in Sweden, OKSTRA in Germany) and complies with international standards like World Wide Web Consortium (W3C) and ISO12006 (Building construction - Organization of information about construction works). Interoperability with InfraGML (and therefore OGC conceptual model) and IFC for Infra formats and therefore bsDD (building Smart Data Dictionary) is important since these are the standards that are used and will be used to store and transfer data.

INTERLINK facilitates a hybrid approach of linking semantically-rich data to more traditional document-based information Ultimately and envisages that road asset data will remain at source, shared over the web through a system of harmonized

data standards with strengths from the international, national and organizational levels, and interrogated via flexible, software-as-a-service applications. To realize this W3C Linked Data (LD) and Semantic Web (SW) technology is use. That means that the OTL will take the form of an 'Ontology' represented in the standard Web Ontology Language (OWL) and enables:

• Agreement on civil infrastructure assets in the road domain, as part of the civil infrastructure sector, itself being part of the broader Architecture, Engineering, Construction / Asset Management sector.

• Instantiation of the OTL into road data sets for exchange and sharing along the lifecycle and supply-chain of the asset.

• Provision of 'decentralized hub' for linking (and where needed, transforming) data & documents to and from not only existing BIM, GIS and Internet of Things standards like bSI, IFC and OGC InfraGML, but also native non-standard/native legacy data sets for smooth migration. This hub of linked data and documents will indirectly also enable new software functionalities: innovation beyond mere integration (advanced calculations, simulations, decision support, big data analytics etc.).

Harmonization with the other most relevant standardization initiatives should focus on the Modelling Guide and on the OTLs (or ontologies) in a layered structure as in the figure below.

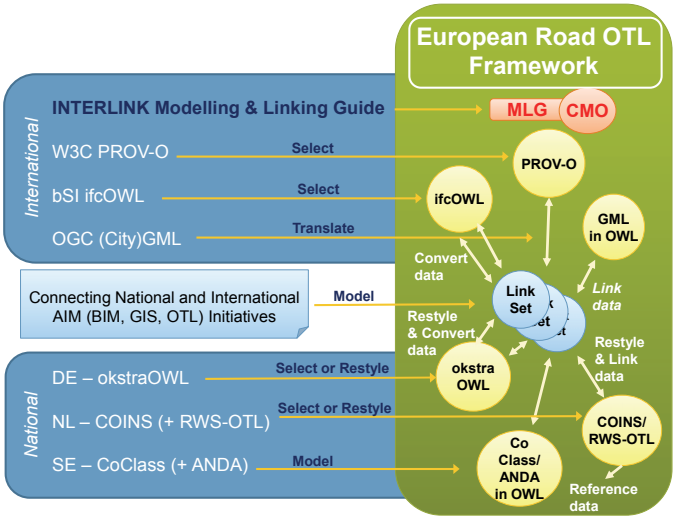

Figure 3. OTL-structure from relevant standardization initiatives to harmonization (O'Keeffe et al, 2017).

For the European Road OTL the INSPIRE road transport data specification and data can be the source to achieve the principles of the European backbone of linking the physical objects to the road transport network and transport elements. Also other environmental themes (spatial data) like protected area, soil, area management restriction zones can be linked to the European RoadOTL during the whole lifecycle.

3 COMMON PRINCIPLES

In this chapter the common principles for a European Road OTL founded on the technologies of linked data and semantic web provided by W3C are described, based on INTERLINK research (Böhms et al, 2017).

3.1 *Common principles of INTERLINK*

INTERLINK's first basic version of the European Road OTL targets the identified NRAs' asset information management needs and issues. From the discussion in the previous sections it can already be derived that there is not just one OTL for some part of reality. There are many purposes, each requiring their own view on reality having their own OTL. In INTERLINK the part of reality of interest is road networks, with three main dimensions observed during the analysis of the needs:

• The life-cycle of an asset: plan, design, build and operate (covering realization, maintenance, renovation, and repurposing);

• The supply-chain for an asset: environment, network, entity, system/sub-system, component and material; and

• The perspectives on the asset's data by the various stakeholders: societal, business, functional, spatial and physical aspects.

The first two dimensions are depicted in Figure 4, which is based on the well-established V-diagram for asset management (Institute of Asset Management, 2016).

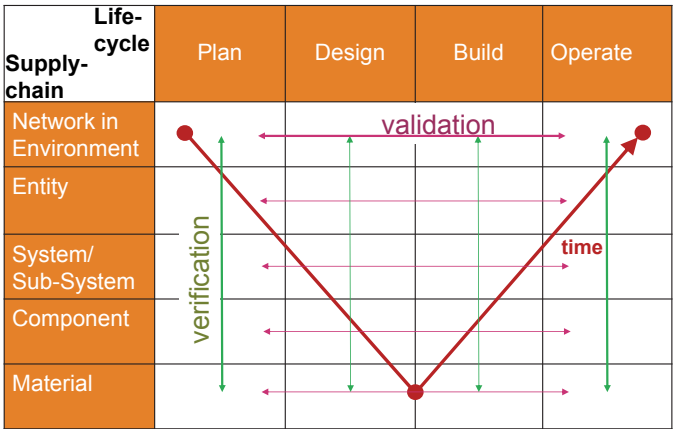

Figure 4. The life-cycle phases and supply-chain dimensions of asset management combined as a V-model (Böhms et al, 2017).

The general information need is that NRA asset data along these dimensions should be (i) better specified: better structured, more complete, more accurate, less ambiguous, up-to-date, consistent, uniformly represented and (ii) better communicated and reused. This should apply along the asset's whole life-cycle and supply-chain. Better communicated here means 'shared with others by linking' instead of 'exchanged to others by conversion', keeping data close to their original source and avoiding cumbersome and error prone data transformations.

3.2 *A shift with the INTERLINK approach*

The INTERLINK approach is to found the European Road OTL on the technologies of linked data and the semantic web provided by W3C—the World Wide Web consortium. This choice was the main conclusion from the European research project V-Con (V-Con, 2016) and is in line with developments towards linked data in the industry's main standardization body buildingSMART International (buildingSmart International, 2016). These W3C technologies will enable CEDR and its NRA members to implement a data-driven and open vendor-neutral system, which is applicable to the whole life-cycle of road assets, and accommodates various existing and future open data standards. In this way the European Road OTL will facilitate a hybrid approach of linking semantically-rich data to more traditional document-based information.

Ultimately, INTERLINK envisages that road asset data will remain at their source, shared over the web through a system of harmonized OTLs with strengths from the international, national and company levels, and interrogated via flexible, software-as-a-service applications. The INTERLINK approach focuses on the commonalities of the national approaches and allows for national differentiation when considered necessary.

3.3 *Common modelling principles for the European Road OTL*

The common principles describe a hybrid approach combining the strengths of currently applied open standards with LD/SW technology. Bringing the available OTLs together in a harmonized framework requires a set of modelling and implementation principles to reuse and interconnect those OTLs.

INTERLINK defined, in line with the European V-Con project and the bSI Linked Data Working Group, the following types of guidelines:

- Many languages/formats, styles and meanings are potentially relevant for dealing with road data. Hence, INTERLINK proposes the hybrid approach, related to hybrid formats ('multiple languages'), hybrid styles ('multiple ways of modelling') and hybrid specifications ('multiple views').
- The W3C linked data / semantic web technology enables the realization of this hybrid approach using:
  - o Resource Description Framework (RDF) as basic language or 'data model' and vocabulary;
  - o RDFS/OWL/SHACL as standard vocabularies to defines object type libraries; and
  - o SPARQL as query language for accessing the linked data.
- Recommendations for modelling styles with linked data:
  - o How to model attributes, enumerated data types, code lists, quantities and units;
  - o A simple and a powerful modelling style are defined.
- Detailed technical modelling and implementation guidelines dealing with a.o. naming conventions, version management, and precise linked data formats to be used.
- Guidelines on linking data sets and OTLs making data sharing possible beyond the traditional data conversion, which results in unwanted duplicates of data with unclear ownership. These principles result in the basic OTL as in the figure below.

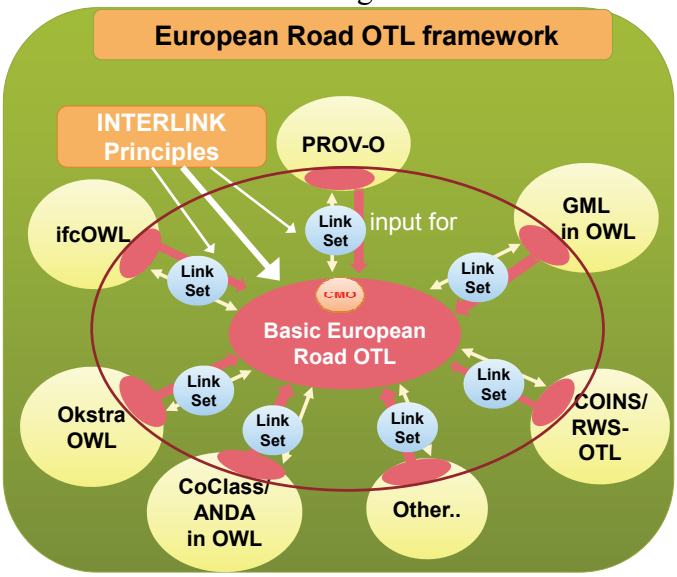

Figure 5. Defining a basic European Road OTL (Böhms et al, 2017).

4 TESTCASES

The INTERLINK approach is validated in test cases in Germany, the Nordic countries and the Netherlands. The objective of the test cases is to prove, for realistic business processes, the added value and the feasibility of implementing the INTERLINK approach with the proposed European Road OTL and the associated open standards. This will be achieved by testing the developed and implemented OTL framework for consistency with the needs statements derived in the first phase. Following are brief descriptions of the test cases.

The German test case 'Handover of BIM Linked Data': An existing bridge in Hamburg is due for demolition and replacement. The design team and NRA aim to use BIM processes during the design stage and specify the handover of BIM-based asset data at the end of construction. The test case involves linking selected bridge objects represented in international and national data standard formats (IFC and OKSTRA, respectively) with an existing bridge classification system (ASB-ing), with road alignment and network data, and with provenance data. Testing entails the finding, viewing, verification and

interrogation of asset object data through various front-end systems.

The Nordic test case 'Linking Asset Data and Network Data': Asset information is procured and managed in order to support the effective operation of a road network. Value can be derived from having improved understanding of the relationships between functional requirements for assets (e.g. traffic capacity), recorded traffic volumes, alignment geometry and location, as-built surface geometry, pavement condition, and pavement deterioration models. The Nordic test case seeks to demonstrate how some of these relationships can be modelled and interrogated using the INTERLINK approach. The test case is relating road alignment data in multiple internationally standardized formats (IFC Alignment, InfraGML) and physical asset information (e.g. for pavement and lighting) to a Linear Reference Network (LRN) model. Asset information will be linked to current national classification systems – SOSI in Norway and CoClass in Sweden. National asset management database systems will be used along with commercially-available modelling software:

The Dutch test case 'Pavement information management using the road OTL with Linked Data': The Dutch test case focuses on pavement management. The test case reflects the pavement asset owner activities of reviewing as-built records and pavement inspection records to determine maintenance requirements. Sharing of inspection data in real time between an inspector's mobile application and the NRA's internal database allows for prompt maintenance decision making, when compared with the current approach of data exchange every three months. The case uses international data standards such as GML and INSPIRE along with national data standards and OTLs such as COINS, CB-NL and the RWS-OTL.

Objects representing pavement segments are linked with data on repair records, pavement performance, and accident records. The validation of repair and performance records is important for future trust in the data. As such, provenance data are linked to selected records by way of demonstration.

These test cases aim at proving that the business and data needs described in chapter 2 can be met with the proposed approach with a European Road OTL, elaborated in chapter 3 with different ontologies. Both added value and feasibility of implementation of the new approach are considered.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 *Conclusions*

The INTERLINK project proposes a new approach towards standardization of information exchange and sharing and proves this concept in test cases based on real-life use cases. Applying linked data and semantic web technologies gives NRAs the opportunity to guide standardization initiatives towards an evolutionary, modular and bottom-up approach.

The European Road OTL, as a software vendor-neutral and open standardized system with a focus on data sharing, will eventually be applicable to the whole life-cycle of infrastructure assets. The powerful semantic web technology demonstrates how to express infrastructure asset object based information and knowledge on a European level. Being able to integrate and reuse existing and forthcoming open standards in flexible ways will minimize obsolescence of earlier investments by NRAs.

Most standardization efforts today rely on a top-down, monolithic approach in which an all-encompassing data structure is defined and imposed upon the whole sector. The INTERLINK approach allows NRAs to build up their own national modular OTLs step-by-step, where possible reusing existing internationally defined and implemented OTLs.

These reused OTLs can be part of existing standardization initiatives or just be best practice in the sector. These OTLs preferably only focus on a limited scope, and are defined and tested by others. Those parts of the OTLs that are reused more often are candidates for being part of the European Road OTL, and thereby will be identified as preferred OTLs. For NRAs, these preferred OTLs are of interest for internal adoption and for inclusion in life-cycle and supply-chain specifications, because OTL maintenance and implementation is shared with other NRAs and with the software industry. It also reduces the likelihood of obsolescence.

Consequently, this will lead to demand-driven software development that meets the asset information, the traffic information and (future) environmental information management needs of NRAs and other stakeholders for not only enhanced interoperability with stakeholders, but also enhanced availability and environment of roads.

5.2 *Recommendations*

For the further development and implementation of the European Road OTL a roadmap is recommended with three periods distinguished:

Short-term: until the end of the research. Based on the experience from these test cases, a Basic Eu-

ropean Road OTL framework is proposed to the initiator of the research, CEDR, as a combination of (parts of) used specifications.

Mid–term: After the project, NRAs can start nationally themselves with the linked data approach and the suggested basic European Road OTL, adapting it to their own needs, and sharing experience with other NRAs. When NRAs are reusing, and where necessary updating, OTLs of others, the OTLs will mature step-by-step in an evolutionary, feedback-driven approach.

Long-term: In the course of time, when commonalities become clear, they are promoted to the European Road OTL. The European Road OTL is also a blue print for countries starting to develop a national OTL.

Together with CEDR, the consortium INTERLINK actively targets setting up an organization that maintains the European Road OTL, preferably in close cooperation with relevant standardization bodies such as buildingSMART, CEN TC442, ISO TC59 and W3C. First objective is standardization of the proposed common modelling principles and, in a later stage, the resulting so called sub-OTLs of the European Road OTL. NRAs could (should) use their influence in relevant standardization bodies to promote the approach and specifically the European Road OTL to the acceptance in practice by the industry.

6 ACKNOWLEDGEMENTS

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